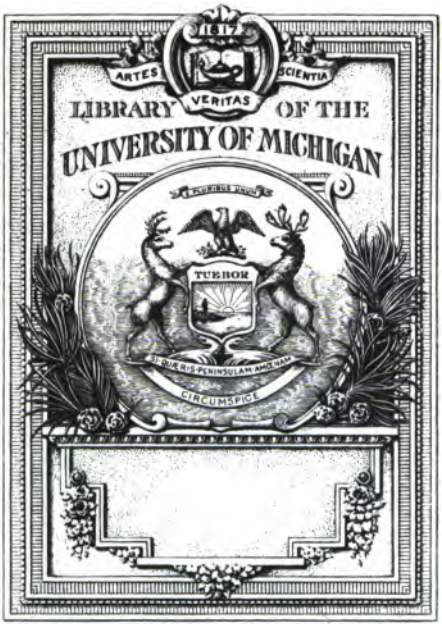
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Prof. G. F. Wright
with kindest regards of
C. F. Dutton

3/11/96.

ERRATA.

Page 23, 3rd line from bottom, for $\frac{1}{2}g+2t$ read $\frac{1}{2}g\times 2t$.

Page 40, bottom line, for *b* read *a*.

Page 42, 12th line from bottom, for Fig. 11, read Fig. 12.

Page 43, 4th line from bottom, for *a* read *A*.

PHYSICS

INTRODUCTORY

TO

PHYSICAL GEOGRAPHY

BY

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Page 83, line 5 for pint read quar[illegible]
" line 7 for two read [illegible]

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PREFACE.

It is the purpose of this little book to give simply and clearly such parts of elementary physics as are essential to a clear understanding of the usual text-books on physical geography. No attempt has been made to write a complete physics. Consequently many things have been omitted which are always found in works on physics. Since the book is intended for pupils who have not studied physics, every effort has been used to make the definitions clear and concise, and to avoid using terms not previously defined. The plan includes such problems and experiments as will fix the laws in mind, and add interest to the work in hand.

C. F. D.

CLEVELAND, February 10th, 1896.

CONTENTS.

CHAPTER I.

MATTER.

1. Anything which has weight is called matter.

All known matter can be perceived by one or more of the senses. Thus we can see or feel a piece of wood, we can sometimes feel the air, we can smell most gases and some vapors. The perfume of a flower is a vapor, is perceived by the sense of smell, has weight, and is therefore matter.

Matter is that which occupies space. Two particles of matter cannot occupy the same place at the same time. Place a marble on the table. You cannot put another marble in the same place without removing the first one, therefore :—

Matter is anything which has weight and occupies space.

COMPOSITION OF MATTER.

2. Matter is made up of **molecules.**

From certain phenomena it seems probable that matter is made up of exceedingly minute particles called molecules. The separate molecules do not touch, but are held near each other by a force called **molecular attraction.** Molecules are inconceivably minute. Their size is thus illustrated by Sir William Thomson :— "Imagine a drop of rain magnified to the size of the earth, the molecules being magnified in the same proportion. The molecules would then be at least as large as fine shot, but not larger than cricket balls."

3. Molecules are made up of atoms.

On account of some chemical actions it seems probable that molecules are groups of still smaller bodies called **atoms**, held together by a force known as **chemical affinity**. A substance whose molecules are made up of similar atoms is called an **element**. Iron, Copper, Zinc, Carbon and many other substances are elements.

A substance whose molecules are made up of different kinds of atoms is called a **compound**. The molecules of common salt are made up of atoms of chlorine, a gas, and atoms of sodium, a metal, held together by chemical affinity. Hence salt is a compound. The molecules of water are made up of atoms of hydrogen, a gas, and oxygen, another gas, held together in the same way, and therefore water is a compound.

MEASUREMENT OF MATTER.

4. Matter is measured in three ways.

1st. The amount of space which a body occupies is its **volume**.

2d. The amount of matter contained in a body is its **mass**.

3d. The amount of matter contained in a given volume of a body is its **density**.

The density of a substance is expressed by stating the number of times a given mass of the substance will be contained in a given volume.

5. Any standard of measure is called a **unit**. Common units of **volume** are the **bushel**, **quart**, **gallon**, **cubic foot**, etc. The scientific unit is the **liter** or the **cubic centimeter**.

Units of **mass** are the **ounce**, **pound** or **ton**, and for scientific purposes the **gram**.

The **density** of a solid or liquid body is expressed by comparing the mass contained in a given volume with the mass of the same volume of water. The density of gases is expressed by comparing them in the same way with the density of air. A cubic foot of water weighs 62.5 lbs. If a cubic foot of stone weighs 3 times as much we say that the density of the stone, compared to that of water, is 3. If a piece of wood weigh $\frac{1}{2}$ as much as its own volume of water its density compared with that of water is $\frac{1}{2}$. The density of any body compared with that of water is called its **specific gravity.** Hence :—

6. The **specific gravity** of any solid or liquid is the ratio of a given mass of the substance to the mass of a volume of water equal in bulk to the portion of the substance taken. Thus the specific gravity of the stone just mentioned is 3, and of the wood $\frac{1}{2}$.

CHAPTER II.

MOTION AND FORCE.

7. When a body is changing its location we say that it has **motion.** There are two kinds of motion.

(a) **Mass motion** is a change in the location of a body taken as a whole.

(b) **Molecular motion** is the movement, among themselves, of the molecules which compose a body. For example, heat, light, and electricity are supposed to be vibrations of the molecules which compose the bodies exhibiting these phenomena.

8. The **velocity** of a moving body is the number of distance units which it passes over in one unit of time. A body going twice as far as another in the same time has twice the velocity.

9. **Force** is that which produces or destroys or tends to produce or to destroy motion. When force actually produces motion, it does **work. Energy** is the power or ability to do work. Work is measured by the amount performed in a given time. A common unit of work is the **horse-power.** One horse-power is a force sufficient to lift 33,000 lbs. one foot in one minute.

10. **Inertia** is that property of matter by which it resists any effort to change its state of rest or of motion. For example—it takes a force of about 50 H. P. **to start** a trolley car but only 8 or 10 H. P. **to maintain** its motion at full speed. The earth, moving through space, keeps on moving because of its

inertia, and it will continue to move until some force arises to overcome this inertia.

11. The **momentum** is the quantity of motion possessed by a body. Take two balls of equal weight and give them equal impulses. They will move with equal velocities. Take two balls, one of 5 lbs. and one of 10 lbs., and roll them with equal velocities. If the forces applied to each be measured it will be found that it took twice the force to start the 10 lb. ball that it did to start the 5 lb. ball. If force be used sufficient to stop them it will require twice as much to stop the 10 lb. ball as to stop the 5 lb. ball. Again, if while the balls are moving with equal velocities the momentum of the 10 lb. ball be transferred to a second 5 lb. ball, the second 5 lb. ball will have twice the velocity of the first 5 lb. ball.

The **momentum** of a body is expressed by multiplying its **mass** by its **velocity.** Thus the momentum of a 5 lb. ball moving 10 ft. per second is 50, and that of a 10 lb. ball moving at the same rate is 100.

LAWS OF MOTION.

12. The motions of all bodies are in accord with the following laws, known as **Newton's Laws of Motion.**

LAW I. Every body continues in its state of rest or of uniform motion in a straight line unless compelled by force to change that state.

LAW II. Every momentum or change of momentum is in proportion to the force applied and takes place in the direction of the straight line in which the force acts.

LAW III. To every action there is always an equal and opposite reaction.

The first law means that if a body is at rest, it will remain at rest until some force moves it, and also

that if a body is in motion it will continue to move until some force stops it. To illustrate: Place a marble in the center of a perfectly level floor. It does not move unless some force is applied to it. Start it rolling. If the floor is perfectly smooth the marble travels in a perfectly straight line. The smoother the floor the longer it continues to roll, and if it were not for the resistance of the air and for irregularities in the floor and in the marble it would never stop. This first law is sometimes called the **law of inertia.**

The second law is best explained by experiment. Strike the marble from the right side and it will move toward the left, that is **in the direction of the straight line in which the force acts.** Strike it twice as hard and it will move twice as fast, that is, **its momentum is in proportion to the force applied.**

The third law is also best shown by illustration. Two row-boats float in a stream. A man in the first boat holds a rope which is tied to the second. He tries to pull the second boat toward his own. If the two boats are of equal size and weight, each boat will move over one half of the intervening space. The action moves one, the re-action the other, and **for the action there is an equal and contrary re-action.** One boat moves in one direction and the other in exactly the opposite.

TRANSMISSION OF FORCE BY ELASTIC BODIES.

13. **Elasticity** is the property possessed by some bodies of returning to their original form or volume after that form or volume has been forcibly changed. Rubber is elastic,—pull a piece of rubber out of its original shape and it flies back on being released.

Steel is elastic,—bend a steel rod and it returns to its original form. Glass is elastic,—if drawn out to a fine thread, it can be bent and will fly back again. If dropped upon a hard surface, a glass marble will rebound because, in striking, the force of the blow flattens one side and in returning to its original form pushes suddenly against the surface struck, and this throws it again into the air. Some bodies are not elastic, as clay, putty, sand, and the like. Such, when forced out of shape, will retain their new form even after the force has been removed. If dropped upon a hard surface they will not rebound. All bodies which rebound are elastic.

14. Whatever causes or tends to cause motion is a force.

The direction in which a force acts may be changed, as is done when a rope is passed over a pulley.

Force may be transmitted from one body to another. This is shown by suspending two elastic balls with cords of equal length so that the two balls are in contact. Pull one ball aside and allow it to swing back and strike the second ball. The first ball stops at the instant of contact, and all its momentum is transmitted to the second ball, which swings on as far as the first would have done if allowed to swing freely.

Force may also be transmitted through several bodies. In a groove or between two rulers place several marbles, so that they touch each other. Roll another marble along the groove and allow it to strike the end of the row. It stops and all of its force is transmitted through the row to the marble at the opposite end, which receives the force and moves with nearly the velocity of the first marble. Force will not be transmitted in this way unless all the bodies are

elastic. Rocks are elastic. This is shown by the way in which earthquake shocks are transmitted through them. The effect which an earthquake has on bodies upon the earth's surface is exactly the same as that shown in the experiment with the marbles. The force is transmitted through the elastic rocks composing the earth's crust, and causes violent motions among objects upon its surface.

ATTRACTION.

15. The commonest of all forces is that of **attraction.** All portions of matter, whether large or small, have an attraction for all other portions. It is of three kinds :—

1st. **Mass attraction** is the attraction between bodies consisting of an assemblage of molecules. Hence the attraction between all visible bodies is mass attraction. This form is often called **gravitation,** especially when the attractive power of the earth and other heavenly bodies is referred to.

2d. **Molecular attraction** is that force which holds together the molecules composing any body. This is the force which causes various substances to retain their form. Without it all bodies would crumble to an infinitely fine dust, the particles of which would consist of separate molecules. There are two forms. The first, called **cohesion,** is the attraction between molecules of the same kind. The second, **adhesion,** is the attraction between unlike molecules. Cohesion holds the molecules of like substances together, while adhesion holds unlike substances in close contact. Thus paint **adheres** to wood and glue holds two surfaces together.

3d. **Atomic Attraction,** usually called chemical affinity, is the force which joins atoms together to form the groups known as molecules.

COMBINED FORCES.

16. We will now consider the effect of two or more forces acting upon a body at the same time.

The second law of motion is usually understood to mean that **any force will produce the same effect upon a body whether the body be at rest or in motion, or whether the force acts alone or in company with others.**

Let any given force act upon a body. According to this law the body will move with a uniform velocity in the direction of the force which started it. At the same instant let a second equal force strike it in a direction at right angles to the first force. In accordance with the same law, the body will move with an equal velocity in the direction of the second force. But it also continues to move with its first velocity in the first direction. Its actual path is shown in Fig. 1.

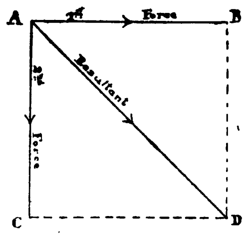

Fig. 1.

Suppose the body to be at A when the forces strike it. Suppose also that the first force would

carry it to B in one second. The second force acting at right angles would carry it, in one second, an equal distance, from A to C. It is plain that the body cannot be at C and at B at the same time, yet the law tells us that it will go as far toward B as if the second force had not acted, and also that it will move as far toward C as it would if the first force were not applied. Therefore D is the only point which can represent the position of the body at the end of one second, for D is the same distance to the right of A as is B, and D is also as far below A as is C. In other words the first force moves the body just as far to the right as if the second were not acting, and at the same time the second force moves the body just as far down as if the first were not acting. The actual path of the body is along line AD. Its rate is represented by the length of AD.

17. When two or more forces act upon a body, the motion which they give it, due to their combined action, is called the Resultant Motion, that is:—

Resultant motion is the motion which a body possesses due to the simultaneous action of two or more forces.

18. **Resultant motion** may follow three different combinations of forces, and is therefore considered in the following three cases.

1st. When two forces act in the **same direction.** The resultant motion is in the same direction and the body receives a momentum equal to the sum of the two forces.

2nd. When two forces act in **opposite directions.** The resultant is in the direction of the greater force and the body receives a momentum equal to the **difference** between the forces.

3rd. When the forces act at **an angle.** The body moves in the direction of each force with the momentum due to each. The resultant is found by drawing a diagram called the **parallelogram of forces.**

It is constructed thus :—

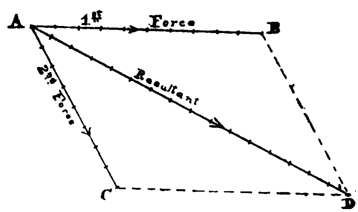

Fig. 2.

Suppose a force having a momentum of 10 in the direction of AB (Fig. 2) acts upon a body at A. At the same instant let a second force having a momentum of 8 in the direction AC act upon the same body.

Draw a line AB having a length of 10. This represents the distance which the first force, acting alone, would move the body in one second.

Draw AC having a length of 8 in the direction of the second force. This represents in the same way the distance traveled and the direction in which the second body would move if acted upon by the second force alone. Complete the parallelogram by drawing BD and CD, and draw the diagonal AD. The diagonal is the resultant. Divide it into parts of the same length as the parts of AB and AC. The number of parts shows the resulting velocity.

19. The resultant is sometimes found by another method called the **triangle of forces.** Using the same forces as in the case just illustrated, draw AB (Fig. 3), as before, to represent the quantity and direction of the first force. Draw BC in the direction of the

second force, giving it a length of 8. Draw AC. It is easily seen that AC in Fig. 8 exactly corresponds with AD in Fig. 2.

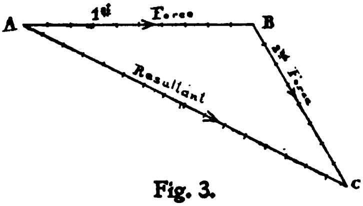

Fig. 3.

20. If more than two forces act at the same time, the resultant of all is found by first finding the resultant of any two of the forces, and then combining this resultant with a third force to get a second resultant. Combine the second resultant with the fourth force and so on until all the forces have been used. The last resultant is the resultant due to all the forces acting together.

A simpler way where there are several forces is to draw a line AB (Fig. 4) to represent the amount and direction of the first force. Add to it BC to show the amount and direction of the second force, CD the third and DE the fourth, drawing as many lines as there are forces. The resultant will be a line drawn from A to the end of the broken line at E. The arrows show the direction of the forces.

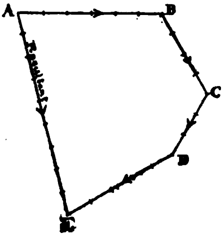

Fig. 4.

21. Fasten any convenient weight to one end of a string. Hold the other end firmly and whirl the weight rapidly around the hand. As the weight revolves it keeps the string drawn out to its full length. The faster the weight is whirled, the harder it pulls on the string. This pull is called the **centrifugal force** and may be explained by Fig. 5.

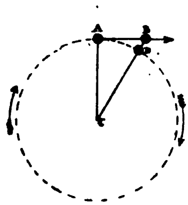

Fig. 5.

C, the center of the circle, is the point about which the cord and weight revolve. *A C* and its equal *D C* represent the length of the string. The motion is in the direction of the arrows. Let the weight be at *A* and moving at any uniform rate, say 8 ft. per second. According to the laws of motion, if the weight be left free to choose its own path, that is, if, when the weight is at *A* it is freed from the cord, it will continue to move in a straight line, in the direction of the motion which it has at the instant of its release from the cord. It will, if not restrained by the cord, move in the direction *AB* at the rate of 8 ft. per second. Since the string forces it to move in a circle, at the end of one second it will be at some point, *D*, on the circumference. If *B* is the point which the weight would have reached if it had been allowed to move freely after passing *A*, it follows that, during the second, the string has pulled it from *B* to *D*. To state the case a little more accurately

the weight has pulled itself from B to D by means of the cord. The centrifugal force is represented by the line BD since it is a force sufficient to move the weight from B to D. Drops of water flying from a grindstone, or particles of mud thrown from a carriage wheel are illustrations of this force. The particles are set in motion by the wheel and remain attached to it only so long as the force of adhesion is greater than the centrifugal force. The reason that the earth is flattened at the poles is that the centrifugal force, due to its rotation, pulled the matter toward the equator and away from the poles during the time when the earth was still highly heated and in a plastic state. **Centrifugal force, then, is that tendency which all revolving bodies have to leave their circular paths and move in a straight line.** The word centrifugal comes from two Latin words, *centrum*, a center, and *fugo*, to chase away from, hence the centrifugal force is that which tends to chase a revolving body away from the center of revolution.

The power required to overcome the centrifugal force is called the **centripetal force,** from the Latin, *peto*, to seek. The force of the sun's gravity compelling the earth to revolve about it, is called its centripetal force.

CONSTANT FORCES.

22. The forces so far studied have been supposed to act for an instant only, and we have considered the motions of the bodies after the forces themselves have ceased to act. In the application of many forces the action is continuous.

A constant force is one which is exerted uniformly and continuously. Thus in a locomotive the force

is applied constantly, even after the train is in motion. From the first law of motion we know that a body once started continues to move with a uniform velocity until stopped by some outside force. It continues to move at a uniform rate without the addition of force after starting. If, however, the force continues to act, the body will continue to gain in velocity.

23. To better understand the action of constant forces let us suppose that, in place of a constant force, we have a uniform force which is applied at regular intervals. A ball receives an impulse at the end of the 1st second, which gives it a velocity of 3 ft. per second. During the 1st second the ball remains motionless. During the 2nd second it has a velocity of 3 ft. per second, and therefore travels 3 ft. At the end of the 2nd second it receives another impulse equal to the first, which gives it an additional velocity of 3 ft. per second. Therefore at the end of the 2nd second it has a velocity of 3+3, or 6 ft. per second. During the 3rd second it travels 6 ft. At the end of the 3rd second the impulse is again received, which gives it a velocity of 6+3, or 9 ft. per second. Continue applying the impulses at the end of each second and we find that the velocity at the end of any second is equal to the velocity at the end of the 1st second multiplied by the number of seconds, or in other words it equals the velocity at the end of the 1st second plus each added velocity.

24. Instead of giving the body an impulse at the end of each second, suppose that an equal amount of energy be evenly applied. At the beginning of the 1st second, the body is at rest. At the end of the 1st second, it has a velocity of 3 ft. per second. Since the force is evenly applied its average rate for the

second is one-half of three or $1\frac{1}{2}$ ft. per second. It therefore travels $1\frac{1}{2}$ ft. the 1st second, but at the end of the second it has a velocity of 3 ft. per second. During the 2nd second the force has the same effect as it did during the 1st second. It therefore adds to the body a velocity equal to that which it gave it during the 1st second. Hence, at the end of the 2nd second, it has a velocity of $3+3$ or six feet per second. During the 2nd second it travels 3 ft. due to the velocity acquired during the 1st second, plus $1\frac{1}{2}$ ft. due to the action of the force in the 2nd second, or $4\frac{1}{2}$ ft. in all. During the 3rd second it gains an additional 3 ft. in velocity, giving it at the end of the 3rd a velocity of $6+3$ or 9 ft. per second. It travels 6 ft. due to the velocity gained the 1st and 2nd seconds, plus $1\frac{1}{2}$ ft. due to the force received during the 3rd, or $7\frac{1}{2}$ ft. in all.

25. From these facts we deduce the following laws:

1st. A body acted upon by a constant force will travel during the first second half the distance which the velocity acquired during the second will carry it in one second.

2nd. The velocity at the end of any second is equal to the velocity at the end of the first second, multiplied by the number of the given second.

3rd. The distance traversed during any second is equal to the distance traversed the first second multiplied by one less than twice the number of the second.

During the	1st	second	it	travels	$1\frac{1}{2}\times(2-1)=1\frac{1}{2}$	ft.
"	" 2nd	"	"	"	$1\frac{1}{2}\times(4-1)=4\frac{1}{2}$	"
"	" 3rd	"	"	"	$1\frac{1}{2}\times(6-1)=7\frac{1}{2}$	"
"	" 4th	"	"	"	$1\frac{1}{2}\times(8-1)=10\frac{1}{2}$	"

From which it follows that :—

At the end of the 1st second it has traveled $1\frac{1}{2}$ ft.
At the end of the 2nd second it has traveled $1\frac{1}{2}+4\frac{1}{2}=6$ ft.
At the end of the 3rd second it has traveled $6+7\frac{1}{2}=13\frac{1}{2}$ ft.
At the end of the 4th second it has traveled $13\frac{1}{2}+10\frac{1}{2}=24$ ft.

$1\frac{1}{2}=1$, or $(1)^2$, times the distance traveled the 1st second.
$6=4$, or $(2)^2$, times the distance traveled the 1st second.
$13\frac{1}{2}=6$, or $(3)^2$, times the distance traveled the 1st second.
$24=16$ or, $(4)^2$, times the distance traveled the 1st second.

From whence we get :—

4th. The space traversed during any number of seconds is equal to the space traveled during the 1st second, multiplied by the square of the whole number of seconds.

The velocity at the end of the first second is called the **increment of velocity** because it is the increase in velocity which is gained during each subsequent second.

The 2nd, 3rd and 4th Laws may be expressed mathematically as follows :—

Let. s=space traversed during any second.
S=total space traversed.
g=increment of velocity.
v=velocity at the end of any second.
t=the number of the second or seconds.

Then we have for the

2nd Law. $v=gt$ or $\frac{1}{2}g+2t$.
3rd " $s=\frac{1}{2}g\ (2t-1.)$
4th " $S=\frac{1}{2}\ gt^2$.

GRAVITATION.

26. The commonest constant force is that attraction which all bodies have for all other bodies. This force is called **gravitation.** No bodies exist which do not possess this attraction.

Two general laws govern the force with which gravitation acts.

1st. The force of gravitation varies as the products of the masses of the two bodies, that is if the mass of one of the bodies be doubled, the product of their masses is doubled and the attraction which they have for each other will be doubled. In the case of a body on the earth's surface, if its mass be doubled, its weight, that is the attractive force between the body and the earth, is doubled, the mass of the earth always being the same.

Stated in other words, if the mass of one or both bodies be increased, the attractive force before the increase is to the attractive force after the increase, as the product of their masses before is to the product of their masses after the increase.

2nd Law. The force of gravitation varies inversely as the square of the distance between the two bodies. If the distance be changed the original attractive force is to the new force as the square of the new distance is to the square of the original distance.

To express these laws algebraically, for the first law :—

Let. f=the attractive force **before** the increase.
F=the attractive force **after** the increase.

m^1=the mass of one body } before the
m^2=the mass of the other body } increase.

w^1=the mass of one body } after the
w^2=the mass of the other body } increase.

Then

(1). $f : F :: m^1\ m^2 : w^1\ w^2$ or

(2). $\frac{f}{F} = \frac{m^1\ m^2}{w^1\ w^2}$ or

(3). $f\ w^1\ w^2 = F\ m^1\ m^2$

For the second law :—

Let. f=the original attraction.
F=the new attraction.
d=the original distance.
D=the new distance.

Then

(1). $f : F :: D^2 : d^2$ or

(2). $\frac{f}{F} = \frac{D^2}{d^2}$ or

(3). $f\ d^2 = F\ D^2$

In each case the three equations are simply different ways of expressing the same thing.

27. We have already learned the laws which govern the motions of bodies when acted upon by a constant force. The formulæ given were as follows :

v=velocity at the end of any second.
g=the increment of velocity
t=the number of the second or seconds
s=space traversed during any second.
S=space traversed during any number of seconds.

$v = gt.$
$s = \frac{1}{2}g\ (2t-1).$
$S = \frac{1}{2}gt^2.$

Gravity for all ordinary distances, is a constant force. Its increment of velocity (g) at this latitude is 32.16 ft. per second. The distance traversed during the first second ($\frac{1}{2}g$) is 16.08 ft.

Hence for **falling bodies** we can substitute, in the equations for constant forces,

32.16 for g, and 16.08 for $\frac{1}{2}$g giving us

$$v=32.16\times t.$$
$$s=16.08\times(2t-1).$$
$$S=16.08\times t^2.$$

The above laws are nicely illustrated in a waterfall. The particles of water as they descend keep moving faster and faster and soon each particle is moving so much more rapidly than those above it that the drops become separated and form spray.

28. In every body there is one point around which the matter composing the body is grouped. It is the center of the body's mass. It is a point so located that if a plane be passed through it, in any direction, it will divide the body into two parts, each of which will contain the same amount of matter, and will therefore have the same mass. This point is called the **center of gravity.** It is not necessarily at the geometrical center. In a globe one hemisphere of which is of wood and the other of lead, the cente of gravity will not be at the center of the sphere. The center of gravity is the center of weight. A stick will balance only when the support is placed under the center of gravity. When two bodies are so placed as to be attracted to each other the attraction acts in the direction of a line connecting their centers of gravity.

29. One example of gravitation is so common that it is often spoken of as if it were the only case of gravitation. It is that of the earth's gravitation, the attraction which exists between the earth and all other bodies. We commonly think of the earth as drawing all other bodies to itself. This seems so because the earth's mass is so great when compared to

the mass of objects upon its surface. The attraction of any object for the earth is just as great as that of the earth for the object. An apple hangs from the limb of a tree. The apple pulls on the earth just as strongly as the earth pulls on the apple. When the apple falls the earth moves toward the apple with the same momentum as that with which the apple moves toward the earth. Since the momentum of a body is the product of its mass and velocity, the distance which the earth moves is very small. If the apple weigh one lb. and the earth 10 millions of millions of lbs. the earth will move only 10 millions of millionths as far as the apple. To use figures which we can comprehend, suppose the apple weighs 1 lb. and the earth 10 lbs; then if the apple is 11 ft. from the ground, the apple will fall 10 ft. and the earth will come 1 ft. to meet it.

Just so the revolution of the moon around the earth. The moon attracts the earth with the same force as that with which the earth attracts the moon. If the mass of the moon were the same as that of the earth each would revolve about a point half way between the two. The mass of the earth is about 80 times as great as the mass of the moon and the distance between the two about 240,000 miles. Therefore, the point about which they mutually revolve is $\frac{1}{80}$ of 240,000 or about 3,000 miles from the center of the earth. This point is their common center of gravity and is about 1,000 miles below the earth's surface.

30. Our second law of gravitation tells us that the force of the attraction varies inversely as the square of the distance between the two bodies. From this it follows that a body will not weigh the same above or below the earth's surface as it does at the surface. Above the surface it follows the law as

stated, below it follows a different law. At the surface its distance from the earth's center of gravity is very nearly equal to the earth's radius, *i. e.* 4,000 miles.

At any point above the earth's surface a body's weight will equal its surface weight divided by the square of the distance from the center of the earth, using the earth's radius as the unit of distance. To express this law in the form of an equation,

Let. G=the attraction of gravity (weight) at any point above the earth's surface.
wt=the surface weight.
D=the distance in terms of the earth's radius.

And we have

$$G=\frac{wt}{D^2}$$

To illustrate—What will a body weighing 10 lbs. at the earth's surface, weigh 4,000 miles above the surface.

The distance from the center of the earth is 8,000 miles or 2 times the radius. Hence D=2 and $D^2=4$. Substituting in the equation we have

$$G=\frac{10}{4}=2\tfrac{1}{2} \text{ lbs.}$$

When a body is below the earth's surface only part of the earth is underneath the body, the other part being above it. The part below the body pulls down and the part above it pulls up. The weight of the body is therefore equal to the difference between the two attractions. By experiment it has been proven that :—**Below the earth's surface the weight of a body decreases directly as the decrease in distance from the center of the earth.**

We suppose the center of gravity to be nearly at the geometrical center. At this point a body would be surrounded in every direction by an equal part of the earth's mass. Each part of the mass would attract equally and hence gravity would pull equally in all directions. Therefore at the center of the earth the body would be without weight. The law tells us that the weight decreases directly as the distance from the center. At a point 2,000 miles from the surface the distance from the center is reduced one-half, and a body has therefore only one-half of its surface weight. Hence we can find the weight at any point below the earth's surface by multiplying the surface weight by that fraction of the radius which lies between the given point and the center of the earth. If,

D=the part of the earth's radius between the given point and the center.
wt=the surface weight.
G=the weight at the given point.

$$G = wt \times D.$$

EQUILIBRIUM.

31. When several forces are acting upon a body in such a way as to balance each other, the resultant is zero and the forces are said to be in **equilibrium**. Since they balance each other they cannot move the body. When the center of gravity is over the base of a body, the body is in equilibrium. If the center of gravity is over any point beyond the base of a body the body is not in equilibrium. Unless supported, it will fall into some position in which the center of gravity will be over the support. A body may be in equilibrium in three different ways:

1st. A body is in **stable equilibrium** when its center of gravity is so far within the outline of the base that the body may be moved somewhat without losing its equilibrium. Thus a body with a broad base is in stable equilibrium.

2nd. A body is in **unstable equilibrium** when its center of gravity is in such a position that the body cannot be moved without causing the center of gravity to come beyond the outline of the base, and the body to lose its equilibrium. Thus a body with a small base is in unstable equilibrium.

3rd. A body is in **neutral equilibrium** when it is of such form, or is in such a position that when its position is changed, the center of gravity will still hold the same relation to its point of support. Thus a sphere always has its center of gravity over its point of support. So also a cylinder lying on its side.

CHAPTER III.

GASES.

32. Matter exists in three forms, the solid, the liquid and the gas.

A **solid** is a body whose molecules have so great an attraction for each other that force is required to separate them.

A **liquid** is a body whose molecules have an attraction for each other sufficient only to give the body a permanent volume, but not sufficient to give it a permanent form.

A **gas** is a body whose molecules have so little mutual attraction that the body will occupy all the space within which the gas is confined.

If we half fill a bottle with water, the water will occupy only half the space, even though we remove the air from the remainder. But if we put gas in the bottle, no matter how much or how little, the gas will diffuse itself evenly throughout the entire space. Any gas may be made to occupy more or less space by relieving or increasing the pressure. Thus many cubic feet of air can be forced into a very small space by applying sufficient pressure, and when the pressure is removed the air will again occupy its original volume.

33. The space occupied by a given quantity of any gas depends upon two things, **pressure** and **temperature.** The volume varies in accordance with two laws.

1st. **The volume of any gas varies inversely as the pressure.** This means that if we double the pressure the space occupied by the gas is reduced one-half, or if we halve the pressure the volume will be doubled. Or, in other words, if we multiply the pressure by any factor, the volume occupied will be equal to the original volume divided by the same factor.

2d. **The volume of any gas varies with the temperature.** Thus a gas expands when heated and contracts when cooled. Winds are the result of this law. Since air is a gas, or rather a mixture of two gases, it expands when heated, and therefore becomes lighter. Hence, hot air rises and cold air falls. If in any given locality the air near the ground becomes heated it will rise and cold air from the surrounding country will come in to take its place. Thus a current of air is formed.

34. Air is a mixture of two gases, **oxygen** and **nitrogen.** It contains by volume about **one** part of oxygen to **four** parts of nitrogen. Oxygen is slightly heavier than air while nitrogen is somewhat lighter. It follows then, that by weight, the proportion of oxygen to nitrogen is slightly more than one to four. It is the oxygen in the air which supports life and combustion. The use of the nitrogen is simply to dilute the oxygen. If the air were pure oxygen our bodies would waste away more rapidly than nature could rebuild them, and a fire once started could never be extinguished. Nearly all the metals would burn, and our stoves would be consumed as easily as the fuel within them.

The air is supposed to extend above the earth's surface for a distance of about fifty miles. It is held in contact with the earth by gravity. Air has weight. If with a delicate balance we weigh a hollow sphere

from which the air has been removed, and then weigh it a second time after allowing it to become filled with air, we find that the second weighing gives us a perceptible increase in weight. In this way we learn that a liter (about a pint) of air weighs 1.29 grams. A nickel five cent piece weighs five grams and hence two quarts of air would weigh about as much as a nickel.

Since, like all gases, air is compressible the weight of the upper layers of air resting on those below, compresses the air nearer the earth's surface. As we ascend we find the density of the air rapidly becoming less. By measuring the density we can estimate the height of points above the earth's surface, for example, the height of a balloon or the altitude of a mountain.

When the air is saturated with moisture, and usually before a storm of wind, the air is lighter, hence a **barometer,** (pressure measure) is used to predict changes in the weather.

35. The barometer, Fig. 6, consists of a glass tube about three feet long, closed at one end and open at the other. The tube is filled with mercury, and the open end placed in a cup of the same metal. Since the upper end of the tube is closed, the air cannot press upon the upper end of the mercury in the tube, but the air does press upon that in the cup. The force is transmitted through the mercury in the cup to the lower end of the tube and holds the column of mercury at such a height that the weight of the column exactly balances the weight of the air. It is easily seen that as the air pressure changes, the mercury column will rise and fall. At the sea level it usually stands at a height of 30 inches or at about 29 inches in our latitude.

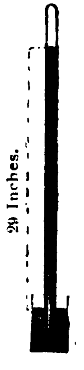

Fig. 6.

36. For some experiments we find it necessary to remove the air from various vessels. To do this, the air pump is used. Its operation depends upon the principle that any gas will distribute itself evenly throughout the vessel in which it is confined. It consists of a cylinder *C*, Fig. 7, in which a piston *P** works air tight.

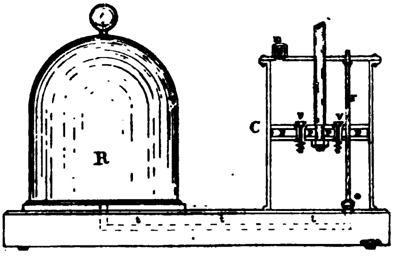

Fig. 7.

Passing through the piston are two openings which are closed by the valves *v v* opening up, but not down. In the bottom of the cylinder is a valve *o*, which opens and closes a tube *t t* leading from the receiver *R*. The valve *o* is opened and closed by a rod *r* which passes through a hole in the piston. The rod fits the hole so tightly that when the piston rises it lifts the rod until an enlargement on the upper end of the rod strikes against the upper end of the cylinder. When the piston rises, the rod lifts the valve *o*, when it descends, the valve is closed. The receiver *R* is the vessel to be exhausted, *i. e.*, emptied of air.

It has already been stated that air, like all other gases, will fill all the space within reach. When the piston *P* is raised, part of the air in *R* passes through

*A piston is a circular disc of metal which fits accurately the inner surface of a cylinder; it is sometimes called a plunger.

the tube *t* and valve *o*, and fills the space below the piston. When the piston descends, it first closes the valve *o* which prevents the return of the air to *R*. As the piston presses upon the air below it, the valves *v v* are forced open and the air escapes into the space above. At the next up stroke, the air above the piston passes into the outer air through the valve *m*.

If the cylinder and receiver are of the same size, it is plain that at each stroke half the air remaining in the receiver will be removed. Hence the vacuum, (absence of air) produced by an air pump can never be absolutely perfect, for, no matter how little air may be left in the receiver, only one-half of it will be removed at the next stroke. Practically, however, the vacuum produced by a good air pump is very nearly perfect.

37. Two general laws are stated concerning the properties of gases.

I. An equal weight of any given gas, under the same conditions of temperature and pressure, always occupies the same space.

II. The volume of a given amount of any gas, under the same conditions of temperature, will vary inversely as the pressure.

The first law needs no explanation, and the second law has, in substance, been previously stated and explained. This second law, known as Mariotte's Law, is not absolutely true, but it is very nearly accurate, the variation being only perceptible at extreme pressures. A good illustration of it is this. Place a rubber bag, partly inflated with air or other gas, under the receiver of the air pump, and partly exhaust the air. Before exhausting the air there was a pressure of 15 lbs. per square inch on the outer surface of the bag. Upon removing part of the air from the

receiver some of the pressure upon the outer surface of the bag is removed. The air within the bag, like any other gas, follows Mariotte's Law, that, as the pressure upon it decreases, the volume increases. The bag, therefore, is expanded until the volume of the air within is the same as the volume of an equal weight of the air surrounding the bag, except the slight difference caused by the elasticity of the bag itself. The outward force by which the air within expands the bag is called **tension.** Tension is the force which causes any gas to completely fill the vessel in which it is contained, no matter how small the quantity of gas or how large the vessel.

CHAPTER IV.

LIQUIDS.

38. As stated in Chapter III, in a liquid, the molecules have sufficient mutual attraction to hold the substance within the same volume, but the attraction is not sufficient to cause the mass to maintain any given form. In other words, a liquid will conform itself exactly to the shape of the vessel containing it, but a given weight of a liquid will always occupy (nearly) the same space.

Liquids are incompressible, that is, no matter how much force is exerted upon them, they cannot be made to occupy a perceptibly smaller space.

39. The commonest liquid is water. Water is made up of two gases, **hydrogen** and **oxygen,** combined chemically. By chemical combination we mean that the molecules of water are made up of atoms of oxygen and atoms of hydrogen held together by chemical affinity. Air is a simple mixture of oxygen and nitrogen gases, there being no union between the oxygen atoms and the nitrogen atoms. **By volume** water contains **two** parts of hydrogen **to one** of oxygen. Since a given volume of hydrogen is only $\frac{1}{16}$th as heavy as an equal volume of oxygen, it follows that water contains, **by weight, one** part of hydrogen **to eight** parts of oxygen.

40. When all points in any surface are equally distant from the earth's center, the surface is said to be **level.**

From this definition it follows that a level surface is not a plane, but a curved surface whose center of

curvature is near the center of the earth. The surface of any body of water at rest is level, therefore the surface of any body of water is a curved surface. This is seen in the horizon line on any large lake or on the ocean. Water not at rest always "seeks its level," that is, all the water on the earth's surface tends to flow toward the earth's center of gravity. Hence, it comes to rest at the lowest level.

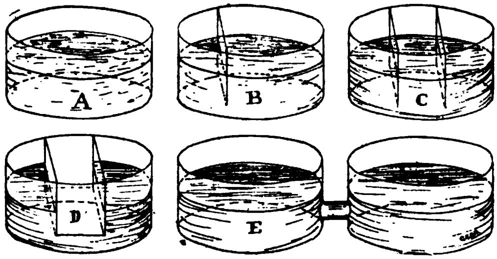

Fig. 8.

If we fill a vessel, *A*, Fig. 8, with water, the surface of the water will be level. It is easily seen that we can insert a thin partition, extending nearly to the bottom, as in *B*, without changing the level, except a very slight increase on both sides of the partition, due to the water which the partition displaces. If we add a second partition as in *C*, we still do not affect the level. Connecting the two by a thin transverse partition, as in *D*, will also not affect the level. If we remove the water from the space enclosed by the partitions in *D*, we have practically two separate vessels connected by a passage and, except in form, equivalent to *E*. This shows that the water in two communicating vessels will stand at the same level in both. In the same way it might be shown that if several vessels be connected by pipes, the water will

stand at the same level in all. This may also be shown by the apparatus in Fig. 9.

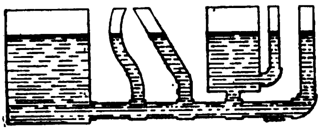

Fig. 9.

When the water has come to the same level in all the vessels it is said to be in **equilibrium.**

41. When pressure is exerted upon a fluid, the pressure is transmitted according to

Pascal's Law. Pressure exerted anywhere on a mass of liquid is (1) transmitted undiminished in all directions, and (2) acts with the same force on all equal surfaces, and (3) in a direction at right angles to those surfaces.

The first part of the law may be illustrated by the apparatus shown in Fig. 10. It consists of a hollow

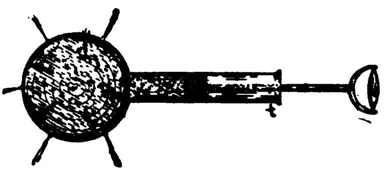

Fig. 10.

globe having several openings scattered over its surface. These openings are closed with corks. The globe is then filled with water, and pressure exerted upon the water by means of the piston *p*, which works in the tube *t*. If the corks are all driven in equally hard, they will all be forced out and the water will be ejected with equal force from all the openings.

The second statement may be shown as follows: A closed cylinder or cask, Fig. 11, has a pipe, *a*, having a sectional area of one square inch, leading into it.

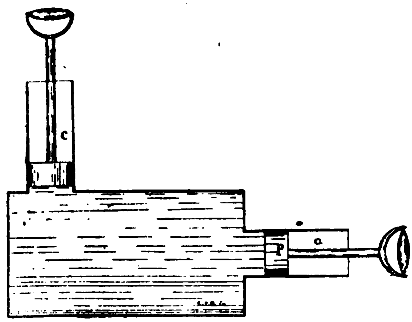

Fig. 11.

The pipe is fitted with a piston, *p*. If we exert a force of one pound on the piston, according to the 2nd clause of the law, the water will exert a force of one pound upon each square inch of the inner surface of the tank. If the area of the inner surface is 100 square inches, the pressure upon the inner surface will be 100 lbs., and for the same reason, if each head of the cylinder has an area of 10 sq. inches, each will receive a pressure of 10 lbs.

The third part of the law may be proved by using any other opening, as *c*, fitted with a tube and piston similar to that at *a*, and like it, having a sectional area of one square inch. If a given force be applied to the piston *b*, we find, by experiment, that it takes the same amount of force at *c* to withstand the pressure transmitted to it through the water. Now, if the force exerted upon the piston *c* were not acting at right angles, a smaller force than that exerted at *b* would

keep c in place, for, since the areas of the two pistons are equal, by the 2nd part of the law, the pressure on each is equal. If the force did not act at right angles, part of the pressure would be lost in pushing the piston against the sides of the pipe, and only a part would be effective in moving the piston along the pipe. Since experiment shows that equal forces on each piston balance each other, it follows that the forces act at right angles to the surfaces.

42. Artesian wells show nicely the laws of equilibrium and pressure.

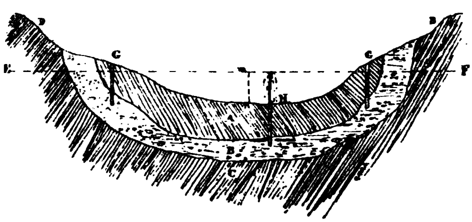

Fig. 12.

In Fig. 12, *A* and *C* are layers of rock or clay through which water cannot pass. *B* is a layer of sand or gravel through which water readily percolates. Water flowing down the hills at *D*, soaks into the ground at the places where the stratum *B* comes to the surface. Since *A* and *C* are nearly water-tight, the water is confined between them until it rises to the level *E F*. If a well be drilled at any point as *G*, the water will rise to the level *E F*, or if the surface of the ground is below *E F*, as at *H*, the water will spout into the air, nearly to the level *E F*. In some places, water flows from such wells with sufficient force to be distributed through pipes and to drive machinery.

From the amount of pressure at the outlet of an artesian well, the height of the water in the strata, *i. e.*, the distance $m\ n$, may be calculated. A cubic foot of water weighs 62.5 lbs. or 1000 ounces. Therefore, a column of water one foot square and two feet high will weigh 2×62.5; 3 ft. high, 3×62.5, etc. That is, a column of water one foot square, and of any given height will weigh as many times 62.5 pounds as it is feet high. If we know the pressure, we can find the height by dividing the pressure per square foot by 62.5. Since the pressure is transmitted equally in all directions, by the same law, we can find the pressure on the side of the column at any depth, for the pressure of water at any point is equal to that of a column of water of a height equal to the distance of the given point below the surface.

The perpendicular distance of any opening, through which water flows, below the surface of the water, is called the **head.** Thus, in Fig. 11, $m\ n$ is the head at the point H.

The velocity with which water flows from any opening is equal to that of a freely falling body which has fallen a distance equal to the head. (See formulæ for falling bodies.) From these facts may be calculated the conditions of the supply of an artesian well, or any other water under pressure.

43. In Fig. 13, A and B are two vessels standing at different levels. C is a tube connecting them. Before placing in position the tube C is filled with water.

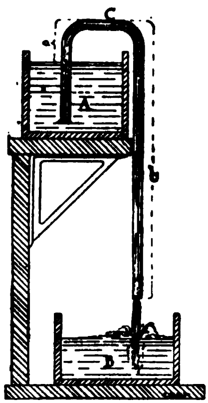

Fig. 13.

Gravity acts upon the water in the arm *a* and also in the arm *b*, tending to produce a vacuum at the top of the tube. The arm *b* is longer, and contains a greater weight of water, hence gravity pulls harder on the water in *b* than it does in *a*. The pressure of the atmosphere, transmitted to the water in the open ends of the tube, is the same in each case. Therefore the downward force is greater in *b*, than in *a*, and the water in *b* falls. The atmospheric pressure upon the surface of the water in *A*, forces water into the arm *a* to prevent a vacuum at the bend in the tube. As fast as it reaches the top, the force of gravity draws the water down the arm *b* and thus a steady stream flows through the siphon until the water in *a* is lowered to the end of the tube.

Some intermittent springs are supposed to act upon the same principle.

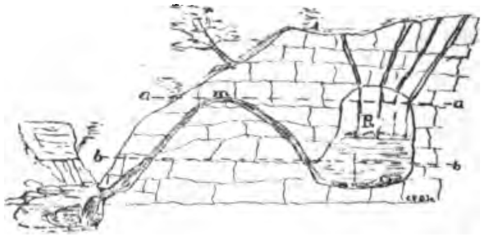

Fig. 14.

Water flows through seams in the rocks into the reservoir *R*, Fig. 14, until it reaches the level *a a*. It then flows through the siphon shaped outlet *m* until the water is lowered below the level *b b*, when the spring will cease to flow until the water again reaches the level *a*.

44. Like the siphon, the action of the pump depends upon atmospheric pressure.

Pumps are of two kinds, the **lifting pump** and the **force pump.**

The essential parts of a force pump are a cylinder,

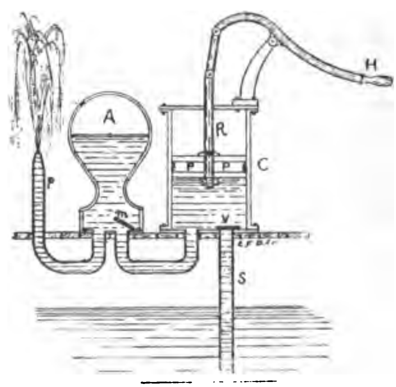

Fig. 15.

C, Fig. 15, within which a piston *P* is moved up and down by means of the rod *R* and handle *H*. A pipe *S*, one end of which dips below the surface of the water to be lifted, passes through the lower end of the cylinder. The upper end of *S* is closed by a valve, *v*, which opens up, but not down; *m* is a valve which prevents water from flowing backwards into the cylinder *C*.

When the piston *P* is raised, a vacuum is formed below it which is immediately filled by water from the pipe *S*, forced up by the pressure of the atmosphere upon the water outside the pipe. When *P* descends, it presses upon the water in *C*, which passes out through the valve *m* into the receiver *A*.

A is filled with air which cannot escape, and is therefore compressed by the inflowing water. From *A* it passes out through the pipe *p*, to any desired place. The object of the receiver *A* is this—water is drawn into the cylinder *C* only while the piston *P* is rising, and the water is forced out of the cylinder only while *P* is descending. Hence the outflow from *C* is in pulses, corresponding to the downward motions of *P*. The compressed air in *A*, however, expands during the time when the piston is rising and, forcing out the water before it, causes a steady stream to flow through *p*.

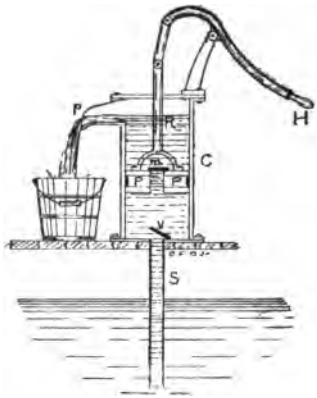

Fig. 16.

The lifting pump, Fig. 16, differs from the force pump in having the second valve *m* in the piston. It operates as follows—when the piston rises it creates a vacuum which is filled, as in the force pump, by water forced through the pipe *S* by the pressure of the atmosphere upon the water outside. When the piston descends the water is prevented from flowing back into the well or cistern by the valve *v*, and at the same time it passes above the piston through the valve *m*. At the next upstroke the weight of the water above the piston closes *m*, and the water is *lifted* up in the cylinder until it flows out through the spout *p*.

FLOATING BODIES.

45. It has already been stated that when pressure is exerted upon a fluid, the force is transmitted equally in all directions. Gravity acts upon a fluid in the same way as any other force, and hence its force is transmitted through the fluid in all directions. It causes an equal pressure upon all surfaces which are equally submerged. The greater the distance of an

object below the surface, the greater the pressure exerted upon it, on account of the increased weight of water above the submerged object. If a body be placed in water the pressure upon the surfaces of the body is, at corresponding depths, the same as that upon the sides of the vessel containing the water. The pressure is transmitted to, and is exerted upon all sides of the body; the amount of pressure at any point depending entirely upon the depth. The pressure upon the opposite sides of the body as *a* and *b*, in Fig. 17, is therefore equal, and the forces thus neutralize each other, so that the pressure upon the sides produces no motion. The pressure upon the under side of a submerged body is greater than that upon the top, because the water is deeper at the bottom than at the top of the body. Hence the pressure on the under side will tend to lift the body toward the surface with a force equal to the difference between the top and bottom pressures. If a body is so light that its weight is less than this difference the body will float; if heavier, it will sink. In either case, its weight is lessened by the difference between the two forces. The exact amount of this difference may be shown by the experiment illustrated in Fig. 17.

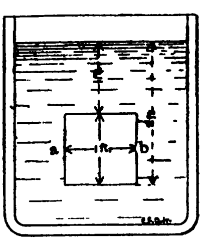

Fig. 17.

In a vessel of water, a cube one foot in each dimension, is immersed until its upper surface is one

foot under water. Since the area of the upper surface is one sq. ft. and it is one foot under water, there is exactly one cubic foot of water resting upon its upper surface. Since a cubic foot of water weighs $62\frac{1}{2}$ lbs., the pressure upon the upper surface of the cube is $62\frac{1}{2}$ lbs. The lower surface of the cube is two feet under water, and since the pressure is transmitted equally in all directions, the upward pressure upon the lower surface is the same as the weight of a column of water one foot square and two feet high. The upward pressure is therefore $2\times62\frac{1}{2}$, or 125 lbs. Since the upward pressure is 125 lbs. and the downward pressure $62\frac{1}{2}$ lbs., the tendency to rise, or the loss in weight, is 125 minus $62\frac{1}{2}$, or $62\frac{1}{2}$ lbs. The volume of the body is one cubic foot, and it therefore displaces one cubic foot of water. A cubic foot of water weighs $62\frac{1}{2}$ lbs., and the body loses in weight $62\frac{1}{2}$ lbs., giving us the following rule:

46. A body immersed in water loses in weight an amount equal to the weight of the water displaced.

This rule gives us a method for finding the specific gravity of any object. The definition given for specific gravity is :—**The specific gravity of a solid or liquid body is the weight of the body divided by the weight of an equal volume of water.**

We find the specific gravity of any solid heavier than water, by first weighing it in air and then weighing it in water. Its loss in weight is equal to the weight of the water displaced. Therefore :—

To find the specific gravity of any object; divide its weight in air by its loss of weight in water. Stated mathematically:

$$\text{Specific gravity} = \frac{\text{Weight in air.}}{\text{Loss of weight in water.}}$$

CHAPTER V.

HEAT.

47. Heat is a form of force. It is supposed to be a motion of the molecules of matter among themselves. The same is true of light and electricity. It is supposed that heat is transmitted by the striking together of the molecules of a body and by their rebounding in much the same way as that by which force is transmitted through the row of marbles in the experiment to illustrate elasticity, (see p. 18.)

It has been claimed that the only difference between heat, light, and electricity, is the difference in the rapidity with which the molecules vibrate. It is certain that they all can be produced by force, and also that heat, light, and electricity can be converted back again into force and motion. While we know many facts about these forms of force, no one knows definitely what heat, light or electricity are. We can, however, state with accuracy many of the laws regarding their action.

48. All substances expand when heated, therefore the specific gravity of a hot body is less than that of the same body when cold. If we have a ring and a ball of such size that the ball will just pass through the ring when both are cold, we find that the ball will not pass through when it is hot. Again when we heat water, the water at the bottom of the vessel becomes heated before the rest, and expanding rises to the top, while the colder, heavier water sinks. In this way currents are formed which may be seen by watching particles of dust or other matter suspended

in the water. Ocean currents are due to the same cause, the water constantly flowing from the cold regions toward the equator and returning after being heated by the tropical sun.

In the same way winds are produced. When the air in any locality is heated it expands, and therefore rises, and cold air flows in to take its place.

49. The intensity of heat is measured by the **thermometer.** The name means *heat-measure*, coming from two Greek words. The thermometer as ordinarily made, consists of a glass tube, one end of which is expanded to form a bulb. The bulb and part of the tube are filled with mercury, the air in the upper end of the tube being removed and the tube sealed air-tight. Mercury expands more when heated than most other fluids, and does not solidify except at a very low temperature. The mercury expands when heated and contracts when cooled, the degree of expansion being shown by the scale. The point at which the mercury stands when placed in melting ice is marked 0° on a Centigrade thermometer, and 32° on a Fahrenheit, while 100° on a Centigrade, or 212° on a Fahrenheit mark the boiling point of water at the sea level. The thermometer measures the degree or intensity of the heat, but not its quantity. The combustion of a given weight of fuel may be used to heat a small object to a high temperature or it will heat a larger body to a lesser degree, but both bodies have received the same amount of heat.

50. Water expands and contracts under the influence of heat in a way peculiar to itself. When cooled it contracts until at 4° Centigrade, or 39.2° Fahrenheit, it reaches its greatest density, and in taking the specific gravity, the water is supposed to be at this temperature. Below this point it rapidly

expands until it freezes, when it occupies a little over a tenth more space than at 39.2°.

For this reason ice floats. The specific gravity of ice is 0.918. One-twelfth of a piece of solid ice will float above the surface, but an iceberg usually lifts about one-seventh of its volume above the surface on account of the buoyancy of the imprisoned air bubbles.

51. When water is heated it changes from its liquid form to that of vapor. Vapor has the form of, and obeys the laws of gases, and therefore its volume varies inversely as the pressure. Under the atmospheric pressure at the sea level, the particles of vapor do not have sufficient tension to escape from the water until it has been heated to 212° Fahrenheit. Above this point, bubbles of vapor escape, and this constitutes boiling. At points above the sea level the atmospheric pressure is less, and therefore the vapor will have an equal volume and tension at a lower temperature. Hence the boiling point is lowered at places elevated above the sea level.

This lowering of the boiling point under diminished pressure, is some times illustrated by partly filling a flask with water and boiling. The flask is then removed from the fire and tightly corked. If cold water be poured over the flask, the steam in the upper part will be so cooled as to be turned back again into water. The steam expelled the air before the flask was corked, and hence when the vapor is condensed, it creates a partial vacuum. This removes the pressure from the surface of the water, and it will begin to boil again, even though the temperature is much below 212°.

52. Vapor rises from water at all temperatures, but more slowly at a low than at a high temperature.

In dry air, even ice will slowly evaporate. Air that is charged with all the vapor it can hold is said

to be **saturated.** Hot air will hold more vapor than cold air, and therefore it takes more vapor to saturate hot air than to saturate cold air. It therefore follows that if the temperature of saturated air be lowered, the air will have to unload some of its vapor. The lowest temperature at which the air will continue to hold its load of vapor is called the **dew point.** If the air be cooled below the dew point the vapor returns again to the liquid state and floats in the air for a time as minute particles of water. Dew, mist, fog, clouds, and the visible form of escaping steam are all aggregations of these small particles of water. Where the particles are sufficiently numerous, they come in contact with each other and unite to form drops, which unite with other drops until their size is sufficient to cause them to fall as rain.

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

THE ELECTRIC CURRENT.

53. Nearly fill a tumbler with a mixture of sulphuric acid and water. Take a strip of zinc and a strip of copper, and fasten a few feet of copper wire to each. Place the two strips in the acid in such a way that they do not touch each other (Fig. 18.)

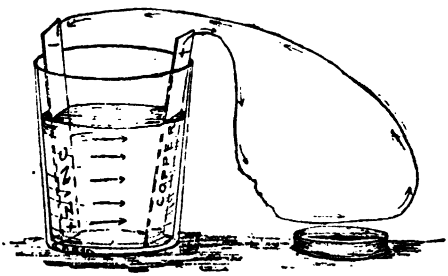

Fig. 18.

Touch the free end of one of the wires to the tongue, at the same time being careful not to come in contact with the other wire. Do this with the second wire. Notice that the wires have no perceptible taste. Now without allowing the wires to come in contact with each other, touch both wires to the tongue simultaneously. A peculiar metallic prickling taste shows that something beside the wires is present, but evidently brought to the tongue by the wires.

Remove either the copper or the zinc strip and again taste the ends of both wires at the same time.

No sensation is produced. These experiments show that to get the taste both wires must be in contact with the tongue, they must also be connected to their respective copper and zinc strips, and the strips must both be in the acid.

Replace the strips in the acid, twist the free ends of the wires together, and bring the loop thus formed near a compass, in such a way as to have the wire parallel to the needle. (See Fig. 18.) The needle immediately turns away. Again remove the copper or zinc, or separate the wires. The loop has no effect upon the needle. Evidently then, the same thing which gave the peculiar taste also affected the magnetic needle.

When the strips are in the acid and the wires connected, we see that something passes along the wires which has power to turn the magnetic needle. The needle has weight, and we have already learned that nothing having weight can be moved without the use of force. Therefore this something which passes over the wires and moves the needle, since it does work, must be a force. We call it **Electricity.**

54. From whence does this force come? If we arrange the metal strips and wires as before, joining the free ends of the wires, we notice bubbles rising from both strips, but much more rapidly from the zinc than the copper strip. Furthermore, if the strips are left in the acid, with the wires connected, after a time the zinc will be partially dissolved, and the tumbler of acid will become warm. This dissolving of the zinc and heating of the acid is a proof that chemical action is going on. Chemical action is the rearrangement of the atoms into new and different molecules. Atoms are held together by the force known as chemical affinity, and when they let go force is set free.

Some of this force is changed into heat and some into electricity. The force therefore comes from the action of the acid upon the zinc. The use of the copper strip is to collect and to transmit the energy.

55. No action takes place unless the electricity can return to the point from which it started. The path which it follows is called the **circuit.** When the path is complete, so that the electric current can pass from the zinc to the copper, and from the copper through the wires back to the zinc, the circuit is said to be **closed.** When the path is not complete, the circuit is said to be **open** or **broken.** We place anything **in the circuit** when we cause the current to pass through it.

56. Any substance which will transmit electrical energy is called a **conductor** of electricity. If it transmits it easily it is a **good conductor,** if with difficulty, it is a **poor conductor.** Any substance which will not transmit electricity is known as a **non-conductor.** When a non-conductor is used to confine an electric current to a particular path, the non-conducting material is called an **insulator.** Thus the glass knobs which prevent the electricity from escaping from a telegraph wire are known as insulators, and wire covered with non-conducting material is called insulated wire.

57. The arrangement of metal strips in the tumbler of acid is called a **battery.** Each strip is called an **element.** We may substitute other metals for the copper and zinc, provided that one of them is more easily attacked by the acid than the other. Pressed carbon may be, and usually is used in place of the less easily affected metal. In place of the acid, any other fluid may be used which has the power of attacking one of the metals, provided that it will conduct the current so generated to the second metal.

A battery is, therefore, any combination of two elements, both of which are conductors of electricity, immersed in any fluid which acts chemically more easily upon one than upon the other.

When a circuit is broken, the end from which the current came is called the **positive** (+) end, the end toward which the current traveled the **negative** (—). The current is generated upon the surface of the zinc below the surface of the acid, and in the acid travels from the zinc to the copper. Hence below the surface of the acid the zinc is positive and the copper negative. Above the surface the current travels from the copper toward the zinc. We therefore call the copper the **positive pole** and the zinc the **negative pole** of the battery. Any wire attached to the copper is +, and any connected to the zinc is —.

58. A piece of iron or steel which has the power of attracting other pieces of iron or steel is called a **magnet.** If we wind a bar of soft (wrought) iron with insulated wire and pass an electric current through the wire, the iron will attract other pieces of iron to itself while the current is passing, and will lose this power whenever the current is cut off. This apparatus is an **electro-magnet.**

If a bar of steel be substituted for the soft iron and the current be passed through the insulated wire, the steel will retain, in part, its property of attracting iron even after the coil of wire has been removed. A piece of steel which has been so treated is a **permanent magnet.**

Load-stone, a kind of iron ore, possesses the same attractive power and is called a **natural magnet.**

Artificial magnets may be made in the way already stated or by rubbing a piece of steel upon a magnet.

59. When a needle, or other short bar of steel is magnetized and balanced at its middle point, one end

always points north. The end which points north is called the **positive** (+) **pole** and the other the **negative** (—) **pole.** A magnetized needle forms the essential part of a compass. When the positive pole of a magnet is brought near the positive pole of another magnet, the two poles repel each other. The same result follows when the two negative poles are brought together. But if the positive of one magnet be brought near the negative of the other, they attract each other. Hence :—**Like magnetic poles are mutually repelled, and unlike poles are attracted.** Since this is true, the north magnetic pole of the earth must be negative.

CAUSES OF THE EARTH'S MAGNETISM.

60. A strip of zinc and a strip of copper are joined together at the ends, as in Fig. 19, and a compass needle balanced between them. When one of

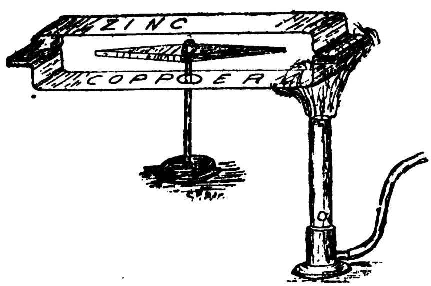

Fig. 19.

the joints is heated, the compass needle is deflected, showing the presence of an electric current. We see then that heat will, under proper conditions, produce electricity. It is known that there are, at times, electric currents passing through the upper layers of the earth's crust from east to west in the direction of

the sun's daily path. These currents are sometimes so strong that telegraph instruments may be operated by their influence alone, without the use of batteries. The earth's crust contains various metals, and the unequal heating of these, as the sun passes over them, has been suggested as the cause of the currents. It is supposed that these electric currents pass around the earth and magnetize the iron in it sufficiently to give to the earth magnetic poles in the same manner as a bar of iron is magnetized by winding it with insulated wire and passing a current through the wire.

If we hold a bar of iron so that it points north and south, and wind it with insulated wire in such a way that when the current traverses the wire it will pass around the bar in the same direction as that in which the sun seems to pass around the earth, the north end of the bar will be negative, and will therefore attract the north end of a compass needle exactly as does the earth.

We see then, that there are electric currents passing around the earth from east to west, that they may be caused by the apparent daily motion of the sun, that their direction is such as would make the earth's north magnetic pole negative, and, knowing that the north pole is negative, we conclude that the earth's magnetism is probably due to the electric currents produced by the heat of the sun's rays as they pass over the earth.

STATIC ELECTRICITY.

61. In the subject just considered we had electricity in motion. That electricity also may exist in a state of rest may be shown in various ways. When at rest it is called **static electricity.** The following experiments will illustrate:

1st. Suspend a piece of pith or tissue paper

from any convenient support by a silk thread. Rub a glass rod, or a long lamp chimney, with a silk cloth and bring the glass near the pith ball, being careful that they do not touch. The pith ball is attracted to the glass.

2nd. Rub a bar of sealing wax, or hard rubber, with a flannel cloth, and bring the bar near the pith ball. The attraction is the same.

When we rub the substances we **electrify** them, that is part of the energy used is converted into electricity which accumulates upon the surface of the rods. In these experiments, we find that both the electrified glass and the electrified wax attract the pith ball.

3rd. Allow the electrified glass to touch the pith ball. Some of the electricity passes from the glass to the pith, and after a moment of contact, the pith ball will fly away from the glass. Now electrify the wax and bring it near the pith ball. The ball is attracted even more strongly than before. This proves that there are two kinds of static electricity, for after touching the glass to the ball, the glass repels it while the sealing wax attracts it.

We may reverse the experiment by touching an electrified bar of sealing wax to the pith ball, when we find that, after contact, the wax repels and the glass attracts.

Electricity produced upon glass is called **positive** (+), and that upon sealing wax **negative** (—).

Since a body positively electrified by contact with electrified glass is repelled by the glass and attracted by a negatively electrified body (rubber or wax), we see that

1st. **Bodies similarly electrified are repelled.**

2nd. **Bodies oppositely electrified are attracted.**

62. If two bodies equally electrified, the one positively and the other negatively, be allowed to touch each other, the two electricities will mingle and will neutralize each other. After contact, both bodies will have equal amounts of positive and negative and will show no signs of electrification.

All apparently unelectrified bodies are supposed to contain equal amounts of the two electricities. Such bodies are said to be **neutral.**

When a positively electrified body is brought near a neutral body, it repels the positive in the neutral body and attracts the negative. If the neutral body is connected to the earth, the positive will escape, but if not, the side of the neutral body nearest the electrified body will become negative, and the side away from it, positive. Similarly, a negatively electrified body will draw the positive of a neutral body toward itself and repel the negative. **As with electrified bodies, so like electricities repel each other and unlike attract.** When a body is electrified by the presence of an electrified body, the process is called **induction.**

Induction may be illustrated by the **electroscope,** an instrument used to show the presence of static electricity. It consists of two strips of gold leaf suspended from the lower end of a metal rod, which passes through the cork of a wide-mouthed bottle. The upper end of the rod carries a ball, (Fig. 20.) When a positively electrified body is brought near the ball, the upper end of the rod and ball become negative, by induction, while the lower end of the rod and the strips of gold leaf become positive. If a negative body be brought near the ball, the ball becomes positive and the leaves negative. In either case, both leaves are similarly electrified, and therefore repel each other whenever an electrified body approaches the ball.

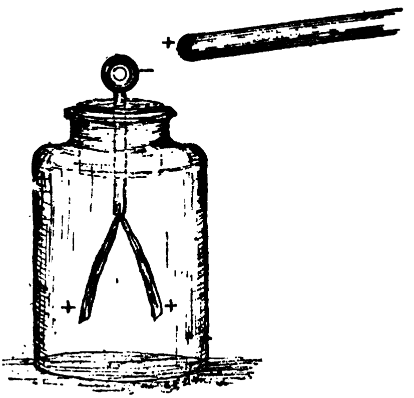

Fig. 20.

63. All substances may be electrified by friction, but, owing to the ease with which electricity passes over the surface of good conductors, they will not retain their electricity unless insulated from the earth. If we hold a metal rod in the hand and rub it with flannel we obtain no signs of electricity, but if the rod be provided with a glass handle it will give the same results as glass or sealing-wax.

Electricity may be accumulated upon the surface of any good conductor which is insulated from the earth. This is shown by the plate electric machine, Fig. 21. The essential parts of a plate machine are, a circular glass plate, *A*, turned by the handle, *B*.

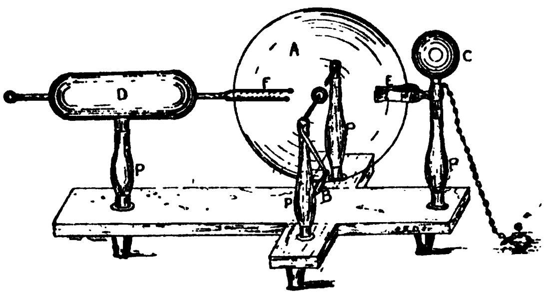

Fig. 21.

At E are two pads which are pressed firmly against the plate A by springs. At F is a series of metal teeth connected with the large metal cylinder, D. The pads, E, are connected to the metal sphere, C, which is connected with the earth by a wire, G. All the parts are insulated from the earth by the glass pillars P. When the plate A is turned, it becomes positively electrified by friction with the pads E and as it passes the metal teeth at F, the electricity leaves the glass and passes through the teeth to the cylinder D.

D is called the **prime conductor,** and is positively charged, while C, called the **negative conductor,** is negative.

After a few turns of the plate, the prime conductor becomes so charged that, if the hand or some other conductor be brought near it, the electricity will jump a distance of a half an inch or so in its endeavor to escape.

64. A glass jar coated inside and out with tinfoil, except for two inches at the top, and having a cork through which passes a metal rod, with a ball on its upper end, and a chain extending from its lower end so as to rest upon the tinfoil on the bottom, is called a **Leyden jar,** Fig. 22.

Fig. 22.

When the jar is held in the hand with the knob in contact with the prime conductor of an electric machine, the inner coat becomes charged with positive electricity, while the outer coat becomes negative by induction. If a curved rod be so placed as to have one end in contact with the outer coating, and the other brought near the knob, a bright spark will pass between the knob and the rod, showing the great attraction between the positive on the inside and the negative on the outer coating.

65. The discharge of a Leyden jar is an illustration of lightning. When the vapor of water is rapidly condensed, the clouds thus formed are heavily charged with electricity which is insulated from the earth by the intervening air. The earth becomes electrified by induction with electricity opposite to that in the clouds. When the attraction between the two becomes sufficient, or the cloud passes over some high object, the two electricities mingle with the familiar flash of lightning. Thus the clouds and earth correspond to the metallic coatings, and the intervening air to the glass of the Leyden jar. Lightning rods allow the two electricities to mingle as rapidly as formed, and hence prevent a violent discharge. When the discharge takes place violently, the particles of air are forced apart by the passage of the current so as to cause a partial vacuum. The concussion caused by their return produces the familiar report of thunder. The reason that thunder rolls is because the spark is so long that the sound from one end of it reaches us before the sound from the other. The roll is also intensified by the echo.

66. For some unknown reason, electricity will pass more readily through rarefied gases than through gases at the ordinary pressure. When electricity

passes through a rarefied gas, it produces the beautiful luminous effects seen in Geissler's tubes. These are glass tubes containing very minute quantities of various gases, and having platinum wires sealed into the ends to afford a passage for the electricity. As the current passes through, the tube glows with a color depending partly upon the kind of gas and partly upon the degree of exhaustion. Crooke's tubes are similar tubes containing only the slightest possible trace of air. The glow in a Crooke's tube at the end where the negative wire enters consists in part of the newly discovered Roentgen, or X, rays which have the power of penetrating opaque substances. The aurora borealis or northern lights are supposed to be caused by electricity passing through the thin air of the upper regions. There are several reasons for this belief. There is a striking resemblance between the colors of the aurora and those produced by the passage of an electric current through rarefied air. The air at the supposed height of the aurora must be very thin, thin enough to give the colors if the electricity were present. Again, at times when the aurora is brightest, the compass needle varies, showing a magnetic disturbance probably due to unusual electric currents. Hence, the belief that the aurora is caused by the passage of electricity through the upper air.